

Heavy flavor baryons

R. Mizuk¹

¹*Institute for Theoretical and Experimental Physics, Moscow*

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In Heavy Quark Effective Theory a heavy quark is considered as a source of the static color field. Heavy flavor baryons provide a laboratory to study the dynamics of the light diquark in the field of the heavy quark.

Heavy quark baryons belong to either SU(3) antisymmetric $\bar{\mathbf{3}}_{\mathbf{F}}$ or symmetric $\mathbf{6}_{\mathbf{F}}$ representations (see Figure 1) [1]. Based on the symmetry properties of the wave

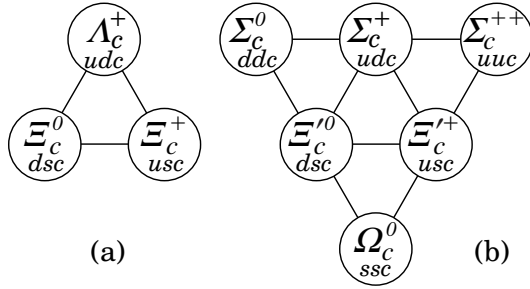


FIG. 1: SU(3) multiplets of charmed baryons, (a) $\bar{\mathbf{3}}_{\mathbf{F}}$ antisymmetric and (b) $\mathbf{6}_{\mathbf{F}}$ symmetric representations.

function, the spin of the light diquark is 0 for $\bar{\mathbf{3}}_{\mathbf{F}}$, while it is 1 for $\mathbf{6}_{\mathbf{F}}$. The total spin of the ground state baryons is 1/2 for $\bar{\mathbf{3}}_{\mathbf{F}}$, while it can be both 1/2 or 3/2 for $\mathbf{6}_{\mathbf{F}}$. The wave functions of higher excitations are also constructed based on the symmetry considerations. There are 8 S-wave isospin multiplets, 35 P-wave isospin multiplets, 85 D-wave isospin multiplets etc [2, 3].

As of 2 years ago [4], all ground state charmed baryons were known, except the Ω_c^* . Also lowest P-wave excitations in the Λ_c and Ξ_c systems were known. In case of the beauty baryons, only the Λ_b state was known. The situation changed dramatically over last two years, when many new states were observed. Here we review the new results on the heavy flavor baryons and on the pentaquarks.

CHARMED BARYONS

Λ_c states

The BaBar Collaboration observed a new state, the $\Lambda_c(2940)^+$, decaying to the $D^0 p$ (see Figure 2) [5]. Also a clear signal of the $\Lambda_c(2880)^+ \rightarrow D^0 p$ decay was observed. In these decays the heavy quark leaves the baryon and is carried away by the meson. Though expected theoretic-

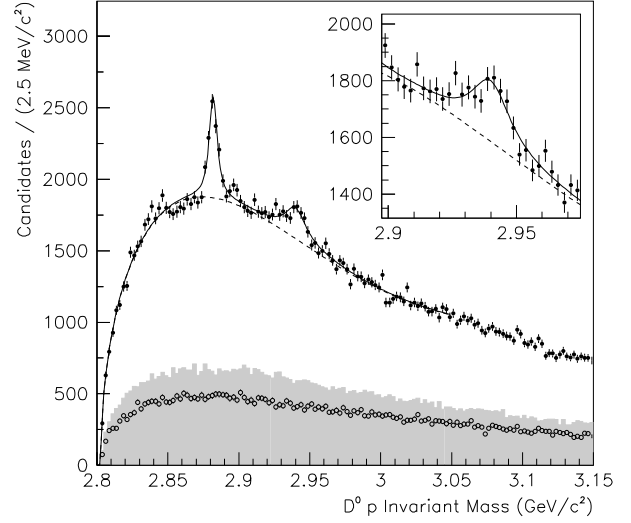


FIG. 2: Invariant mass distribution for $D^0 p$ candidates at BaBar [5]. Also shown are the contributions from D^0 sidebands (grey) and wrong-sign combinations (open dots).

cally, this is the first experimental observation of such decays. The signals of the $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ were not observed in the $D^+ p$ final state, which unambiguously establishes that these states have isospin zero and are indeed the Λ_c states, and not the Σ_c . The $\Lambda_c(2880)^+$ has originally been observed by the CLEO Collaboration in the $\Lambda_c^+ \pi^+ \pi^-$ final state [6], however it was not included in the PDG Summary Tables since its isospin was not known.

The Belle Collaboration has confirmed the observation of the $\Lambda_c(2940)^+$ using a different final state, the $\Lambda_c^+ \pi^+ \pi^-$, and requiring an intermediate $\Sigma_c(2455)^{++}$ or $\Sigma_c(2455)^0$ resonance (see Figure 3) [7]. The $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ mass and width measured by BaBar and Belle are consistent (see Table I). Since the mass of the

TABLE I: Mass and width of the $\Lambda_c(2880)$ and $\Lambda_c(2940)$ measured at BaBar and Belle. Here and throughout the paper the first uncertainty is statistical, the second one is systematic.

		M , MeV/ c^2	Γ , MeV
BaBar	$\Lambda_c(2880)$	$2881.9 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$
Belle	$\Lambda_c(2880)$	$2881.2 \pm 0.2 \pm 0.4$	$5.8 \pm 0.7 \pm 1.1$
BaBar	$\Lambda_c(2940)$	$2939.8 \pm 1.3 \pm 1.0$	$17.5 \pm 5.2 \pm 5.9$
Belle	$\Lambda_c(2940)$	$2938.0 \pm 1.3^{+2.0}_{-4.0}$	13^{+8+27}_{-5-7}

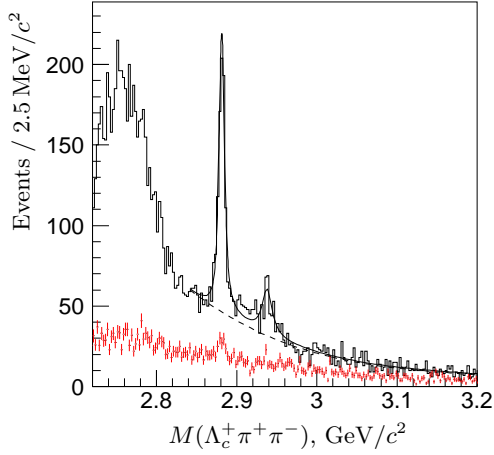


FIG. 3: The invariant mass of the $\Lambda_c^+ \pi^+ \pi^-$ combinations for the $\Sigma_c(2455)$ signal region (histogram) and scaled sidebands (dots with error bars) at Belle [7].

$\Lambda_c(2940)^+$ is at the D^*p threshold, an exotic interpretation of this state as a D^*p molecule was proposed [8]. More experimental studies are required to determine the $\Lambda_c(2940)^+$ quantum numbers and understand its structure.

The Belle Collaboration studied in more details the properties of the $\Lambda_c(2880)^+$ [7]. The helicity angle distribution of the $\Lambda_c(2880)^+ \rightarrow \Sigma_c(2455)\pi$ decays was found to be non-uniform (see Figure 4). The fact that

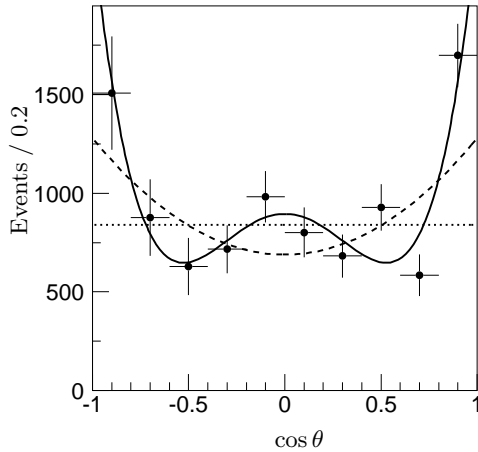


FIG. 4: The yield of the $\Lambda_c(2880)^+ \rightarrow \Sigma_c(2455)^{0,++} \pi^{+,-}$ decays as a function of the helicity angle. The fits correspond to different $\Lambda_c(2880)^+$ spin hypotheses.

the $\Lambda_c(2880)^+$ is produced polarized allows to measure its spin. From the fit to the angular distribution, the $J = 5/2$ hypothesis is favored over the $J = 3/2$ hypothesis at the 4.5σ level, while the $J = 5/2$ hypothesis is favored over the $J = 1/2$ hypothesis at the 5.4σ level. Belle also observed for the first time the 3σ signal of the intermediate $\Sigma_c(2520)$ state in the $\Lambda_c(2880)^+ \rightarrow \Lambda_c^+ \pi^+ \pi^-$

decays, and measured the ratio of the $\Lambda_c(2880)^+$ partial width $\Gamma[\Sigma_c(2520)\pi]/\Gamma[\Sigma_c(2455)\pi] = 0.23 \pm 0.06 \pm 0.03$. This value favors the spin-parity assignment of $5/2^+$ over $5/2^-$ [9]. The $5/2^+$ assignment for the $\Lambda_c(2880)^+$ was proposed in Ref. [10] based on a string model for baryons half a year before Belle results were announced.

Σ_c states

The Belle Collaboration observed an isotriplet of excited charmed baryons, the $\Sigma_c(2800)$, decaying to the $\Lambda_c^+ \pi$ final state (see Figure 5) [11]. Additional peak at $\Delta M \sim 0.42 \text{ GeV}/c^2$, visible in the $\Lambda_c^+ \pi^+$ and $\Lambda_c^+ \pi^-$ invariant mass distributions, is identified with the feed-down from the $\Lambda_c(2880)^+ \rightarrow \Sigma_c(2455)\pi \rightarrow \Lambda_c^+ \pi^+ \pi^-$ decays. The parameters of all isospin partners are consistent (see Table II). Based on the mass and width, the

TABLE II: Mass, width and cross-section times branching fraction for $\Sigma_c(2800)^0$, $\Sigma_c(2800)^+$ and $\Sigma_c(2800)^{++}$.

	$\Delta M, \text{ MeV}/c^2$	$\Gamma, \text{ MeV}$	$\sigma \times \mathcal{B}, \text{ pb}$
$\Sigma_c(2800)^0$	$515.4^{+3.2+2.1}_{-3.1-6.0}$	61^{+18+22}_{-13-13}	$2.0^{+1.1}_{-0.9}$
$\Sigma_c(2800)^+$	$505.4^{+5.8+12.4}_{-4.6-2.0}$	62^{+37+52}_{-23-38}	$2.6^{+3.1}_{-1.9}$
$\Sigma_c(2800)^{++}$	$514.5^{+3.4+2.8}_{-3.1-4.9}$	75^{+18+12}_{-13-11}	$2.4^{+1.1}_{-0.9}$

$3/2^-$ assignment for these states was proposed [11]. Note that the mass of the new resonances is at the $D^0 p$ threshold.

Ξ_c states

The Belle Collaboration observed two new Ξ_c states, the $\Xi_c(2980)$ and $\Xi_c(3080)$, decaying to the $\Lambda_c^+ K^- \pi^+$ and $\Lambda_c^+ K_S^- \pi^-$ (see Figures 6, 7) [12]. In contrast to decays of other known excited Ξ_c states, the observed baryons decay to separate charmed (Λ_c^+) and strange (K) hadrons. The BaBar Collaboration confirmed observations of the $\Xi_c(2980)$ and $\Xi_c(3080)$ [13]. The Belle and BaBar results for the $\Xi_c(2980)$ and $\Xi_c(3080)$ parameters are consistent (see Table III). In addition, BaBar stud-

TABLE III: Mass and width of the $\Xi_c(2980)^+$ and $\Xi_c(3080)^{+,0}$ measured at BaBar and Belle.

	$M, \text{ MeV}/c^2$	$\Gamma, \text{ MeV}$
Belle $\Xi_c(2980)^+$	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$
BaBar $\Xi_c(2980)^+$	$2967.1 \pm 1.9 \pm 1.0$	$23.6 \pm 2.8 \pm 1.3$
Belle $\Xi_c(3080)^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$
BaBar $\Xi_c(3080)^+$	$3076.4 \pm 0.7 \pm 0.3$	$6.2 \pm 1.6 \pm 0.5$
Belle $\Xi_c(3080)^0$	$3082.8 \pm 1.8 \pm 1.5$	$5.2 \pm 3.1 \pm 1.8$
BaBar $\Xi_c(3080)^0$	$3079.3 \pm 1.1 \pm 0.2$	$5.9 \pm 2.3 \pm 1.5$

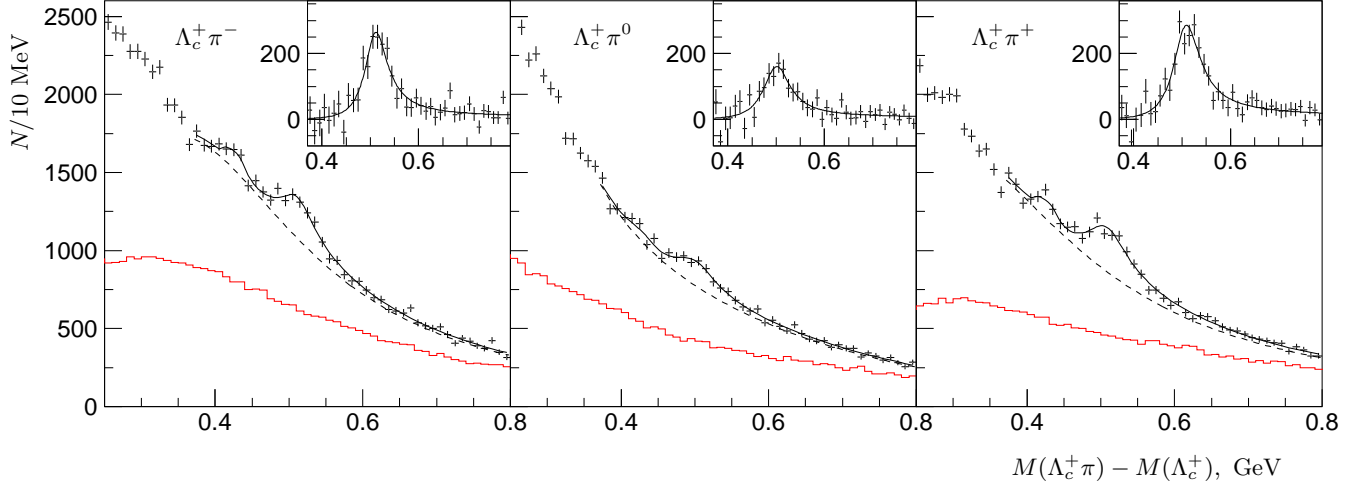


FIG. 5: $M(\Lambda_c^+ \pi) - M(\Lambda_c^+)$ distributions of the $\Lambda_c^+ \pi^-$ (left), $\Lambda_c^+ \pi^0$ (middle) and $\Lambda_c^+ \pi^+$ (right) combinations. Data from the Λ_c^+ signal window (points with error bars) and normalized sidebands (histograms) are shown. The insets show the background subtracted distributions.

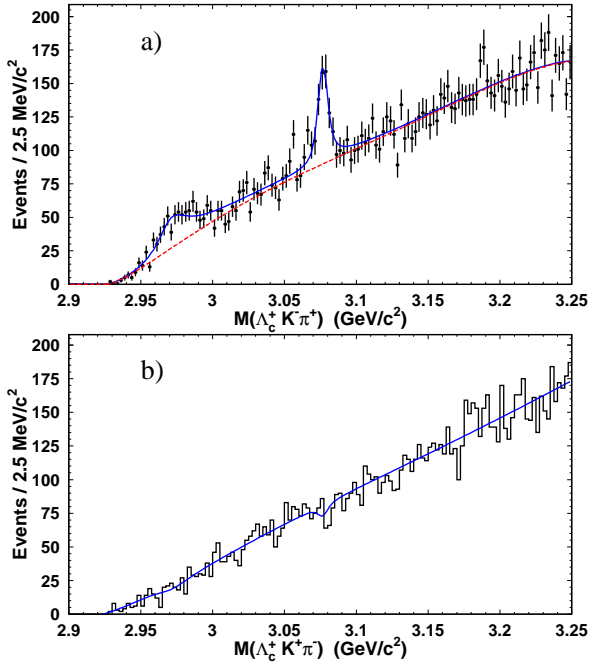


FIG. 6: (a) $M(\Lambda_c^+ K^- \pi^+)$ distribution at Belle [12]. (b) $M(\Lambda_c^+ K^+ \pi^-)$ (wrong sign) distribution.

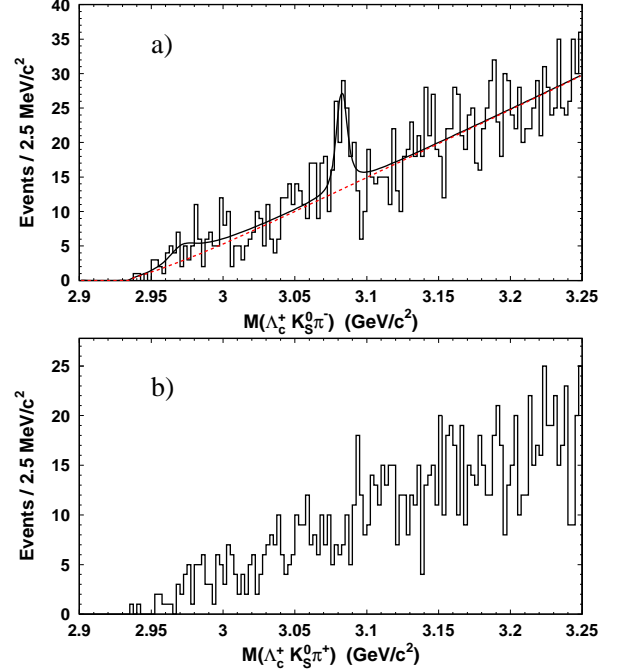


FIG. 7: (a) $M(\Lambda_c^+ K_S^0 \pi^-)$ distribution at Belle [12]. (b) $M(\Lambda_c^+ K_S^0 \pi^+)$ (wrong sign) distribution.

ied the resonant structure of the $\Lambda_c^+ K^- \pi^+$ final state. The $\Xi_c(3080)$ was found to decay through the intermediate $\Sigma_c(2455)$ and $\Sigma_c(2520)$ states with roughly equal probability. The $\Xi_c(2980)$ was found to decay through the intermediate $\Sigma_c(2455)$ and nonresonantly, while the intermediate $\Sigma_c(2520)$ state is forbidden kinematically. The numerical results on the resonant structure can be

found in Table IV. Based on its mass and width, the $\Xi_c(3080)$ state is proposed to be a strange partner of the $\Lambda_c(2880)^+$ with the spin-parity $5/2^+$ [9, 14]. The $\Xi_c(2980)$ is proposed to be also a D-wave excitation, $1/2^+$ or $3/2^+$ [9, 14]. More experimental studies are required to constrain J^P of these new states.

If an intermediate $\Sigma_c(2455)$ or $\Sigma_c(2520)$ is required,

TABLE IV: Results of the resonant structure study of the $\Xi_c(2980)^+$ and $\Xi_c(3080)^+$ decays to the $\Lambda_c^+ K^- \pi^+$.

	Yield (Events)	Significance
$\Xi_c(2980)^+ \rightarrow \Sigma_c(2455)^{++} K^-$	$132 \pm 31 \pm 5$	4.9σ
$\Xi_c(2980)^+ \rightarrow \Lambda_c^+ K^- \pi^+$	$152 \pm 37 \pm 45$	4.1σ
$\Xi_c(3080)^+ \rightarrow \Sigma_c(2455)^{++} K^-$	$87 \pm 20 \pm 4$	5.8σ
$\Xi_c(3080)^+ \rightarrow \Sigma_c(2520)^{++} K^-$	$82 \pm 23 \pm 6$	4.6σ
$\Xi_c(3080)^+ \rightarrow \Lambda_c^+ K^- \pi^+$	$35 \pm 24 \pm 16$	1.4σ

then more structures in the $\Lambda_c^+ K^- \pi^+$ mass spectrum become visible (see Figure 8). The BaBar Collabora-

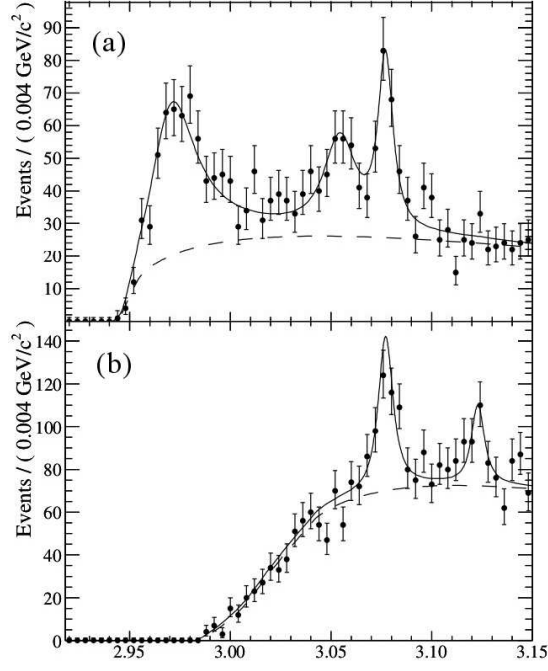


FIG. 8: The $\Lambda_c^+ K^- \pi^+$ invariant mass distribution for $M(\Lambda_c^+ \pi^+)$ consistent (a) with the $\Sigma_c(2455)$ and (b) with the $\Sigma_c(2520)$, measured at BaBar [15].

tion observed a new state, the $\Xi_c(3055)$, decaying to the $\Sigma_c(2455)\pi$ [15]. BaBar also found the 3.6σ evidence of another new state, the $\Xi_c(3123)$, decaying to the $\Sigma_c(2520)\pi$ [15]. The parameters of the new states are listed in Table V.

TABLE V: Mass, width and significance of the $\Xi_c(3054)^+$ and $\Xi_c(3123)^+$.

	M , MeV/ c^2	Γ , MeV	Significance
$\Xi_c(3055)^+$	$3054.2 \pm 1.2 \pm 0.5$	$17 \pm 6 \pm 11$	6.4σ
$\Xi_c(3123)^+$	$3122.9 \pm 1.3 \pm 0.3$	$4.4 \pm 3.4 \pm 1.7$	3.6σ

The charmed hadrons at B-factories can be produced not only in the continuum e^+e^- annihilations, but also in the decays of the B mesons. The decay $B \rightarrow \Lambda_c^+ \bar{\Lambda}_c^- K^-$ was observed by Belle [16]. BaBar confirmed the observa-

tion and studied the resonant structure of this decay [17]. A broad peak was found in the $\Lambda_c^+ K^-$ mass distribution, which is inconsistent with the phase space (see Figure 9). Note that no structure is found at the same mass for

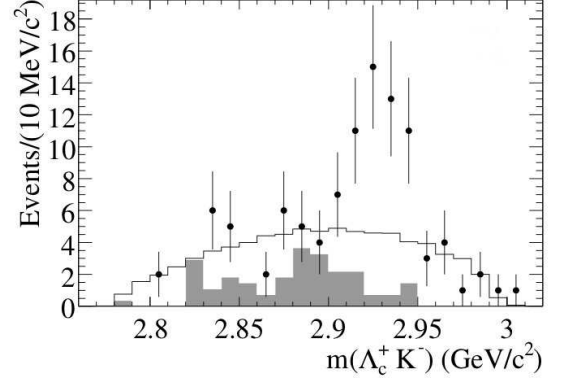


FIG. 9: The $\Lambda_c^+ K^-$ invariant mass distribution for reconstructed $B^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^- K^-$ decays at BaBar [17]. Data from the B^- signal (sideband) region are shown as points with error bars (shaded histogram), the phase-space simulation is shown as a line.

$\Lambda_c^+ K^-$ pairs produced in the continuum. As stated by BaBar, more data are needed before firm conclusions can be drawn.

Ω_c states

The last missing ground state charmed baryon, the Ω_c^* , was observed by BaBar in the $\Omega_c \gamma$ final state (see Figure 10) [18]. The significance of the signal is 5.2σ (cal-

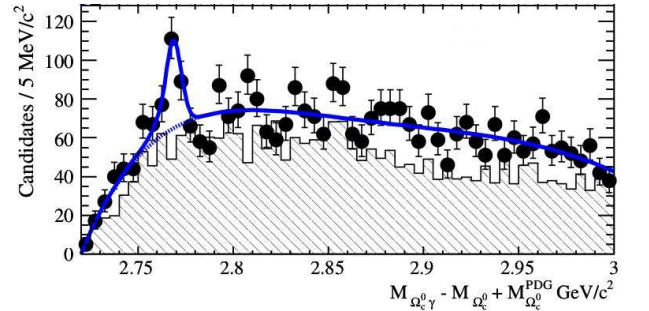


FIG. 10: The $\Omega_c \gamma$ invariant mass distribution for the Ω_c signal region (points with error bars) and sidebands (histogram) at BaBar [18].

culated for one degree of freedom). The measured mass difference between Ω_c^* and Ω_c , $70.8 \pm 1.0 \pm 1.1$ MeV/ c^2 is in good agreement with the theoretical predictions [19, 20, 21, 22, 23, 24, 25, 26, 27].

BEAUTY BARYONS

While all the discussed results for the charmed baryons came from the B-factories, the TEVATRON experiments contributed to the study of the beauty baryons.

Σ_b states

The Σ_b and Σ_b^* , the ground state isovector beauty baryons, were observed by the CDF Collaboration in the $\Lambda_b^0 \pi^+$ and $\Lambda_b^0 \pi^-$ final states (see Figure 11) [28]. To

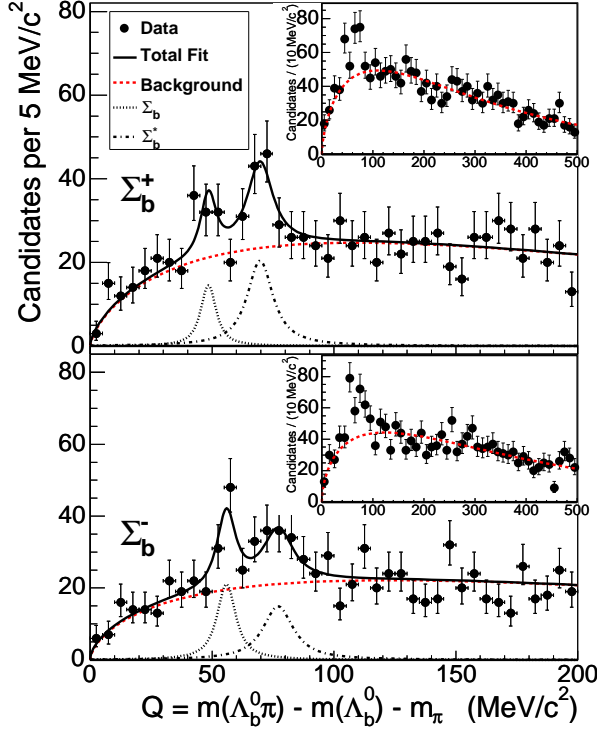


FIG. 11: The invariant mass distributions for the $\Lambda_b^0 \pi^+$ (top) and $\Lambda_b^0 \pi^-$ (bottom) combinations at CDF [28].

avoid psychological bias, blind analysis was performed; the signal region in $M(\Lambda_b^0 \pi)$ was looked at only after the selection requirements and the model for the background were fixed. The signal region exhibits a clear excess of events. The excess is fitted to a four-peak structure (two peaks in $M(\Lambda_b^0 \pi^+)$ and two peaks in $M(\Lambda_b^0 \pi^-)$; simultaneous fit is performed). The widths of the Breit-Wigner shapes is fixed to the predictions based on the Heavy Quark Symmetry [29]:

$$\Gamma = \frac{1}{6\pi} \frac{M_{\Lambda_b}}{M} |f_p|^2 |\vec{p}_\pi|^3.$$

(The width is increasing with the mass of the resonance.) Based on the theoretical expectations [30], the mass differences $M(\Sigma_b^{*+}) - M(\Sigma_b^+)$ and $M(\Sigma_b^{*-}) - M(\Sigma_b^-)$ are

constrained to be the same. Both the shape and the normalization of the background are fixed; the main component of the background is determined from the calibrated Monte-Carlo simulation. The free parameters of the fit are four normalizations of the peaks and three masses (four masses minus one constraint). The results of the fit are given in Table VI. The significance of the four-peak

TABLE VI: Results of the $\Sigma_b^{(*)}$ fit.

$m(\Sigma_b^+) - m(\Lambda_b^0) = 188.1_{-2.2}^{+2.0+0.2} \text{ MeV}/c^2$
$m(\Sigma_b^-) - m(\Lambda_b^0) = 195.5 \pm 1.0 \pm 0.2 \text{ MeV}/c^2$
$m(\Sigma_b^{*+}) - m(\Sigma_b^+) = 21.2_{-1.9}^{+2.0+0.4} \text{ MeV}/c^2$

structure relative to the background only hypothesis is 5.2σ (for 7 degrees of freedom). The significance of every individual peak is about 3σ . The measured Σ_b and Σ_b^* masses are in good agreement with theoretical predictions [19, 20, 22, 26, 31, 32].

Ξ_b states

The baryon, which contains the quarks from all three generations, the Ξ_b , was observed by the D0 and CDF Collaborations in the decay to the $J/\psi \Xi^-$ (see Figure 12) [33, 34]. The measured parameters of the Ξ_b^-

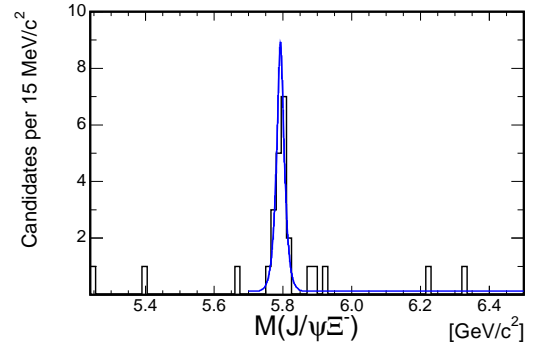
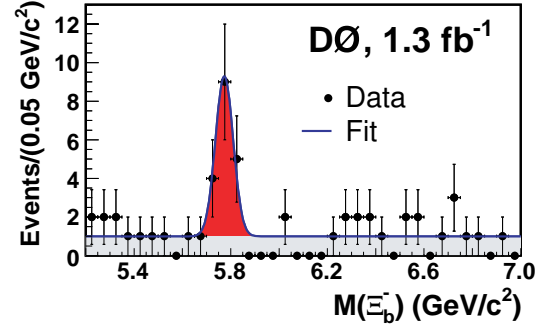


FIG. 12: The invariant mass distributions of the $J/\psi \Xi^-$ combinations at D0 (top) [33] and CDF (bottom) [34].

are given in Table VII. The results of D0 and CDF are

TABLE VII: The parameters of the Ξ_b^- measured by D0 and CDF.

	Yield	Mass, MeV/c ²	Significance
D0	$15.2 \pm 4.4^{+1.9}_{-0.4}$	$5774 \pm 11 \pm 15$	5.5σ
CDF	17.5 ± 4.3	$5792.9 \pm 2.5 \pm 1.7$	7.7σ

consistent and are in agreement with the theoretical expectations [20, 22, 31].

The spectra of all “old” and “new” heavy quark baryons are shown in Figure 13 (colored online). The

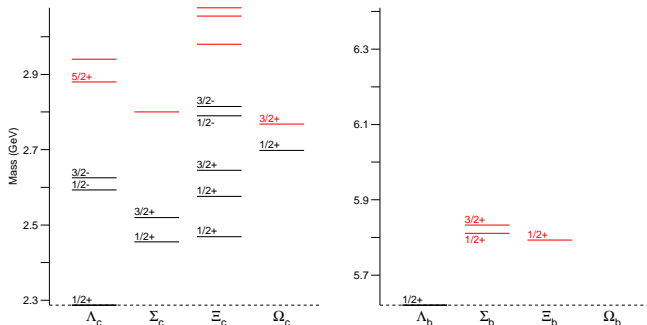


FIG. 13: Mass spectrum of all known charmed and beauty baryons. Recently observed states are in red.

ground state flavor SU(3) multiplets of the charmed baryons are now complete. The number of known beauty baryons increased from one to four over a few last months; as a result, the mass splittings between the ground state beauty baryons were measured for the first time. The measured masses are in agreement with the theoretical expectations. We understand the ground state heavy quark baryons, both in the Quark Model and in the Lattice QCD, though with worse accuracy. The new era in the excited charmed baryons has started. The properties of the $\Lambda_c(2880)$ $J^P = 5/2^+$ are in agreement with the expectations. The main issue for the other recently observed excited charmed baryons is the determination of their quantum numbers. Here a coherent theoretical and experimental effort is required.

PENTAQUARKS

The minimal quark content of the $\Theta(1540)^+$ pentaquark is $|uudd\bar{s}\rangle$. The $\Theta(1540)^+$ was predicted in the Chiral Soliton Model [35] and subsequently many experiments found evidences for its existence [1]. Its mass is about $1530 - 1540$ MeV/c² and its width is below $\Gamma < 1$ MeV [1]. The present experimental situation is controversial, since many experiments do not see the signal of the $\Theta(1540)^+$ [1]. We consider here the new results which appeared after the PDG2006 review [1].

The DIANA group increased statistics effectively by a factor of 1.6 [36]. The $\Theta(1540)^+$ signal was con-

firmed (see Figure 14). With modified analysis, the sig-

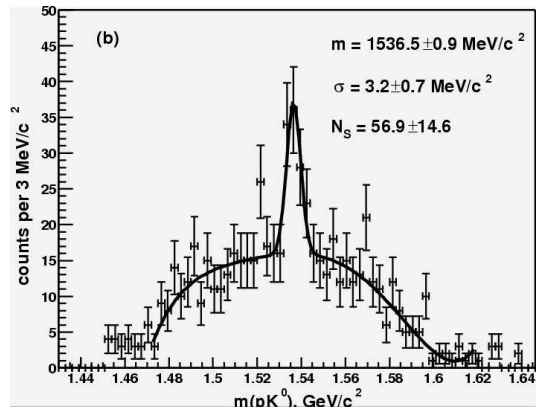


FIG. 14: The invariant mass distributions of the pK_S pairs at DIANA [36].

nificance increased from 4.4σ to 7.3σ (the significance is estimated as S/\sqrt{B} , where S and B are the numbers of the signal and background events, respectively). DIANA performed also an estimation of the $\Theta(1540)^+$ width, $\Gamma = 0.36 \pm 0.11$ MeV. This number is much lower than the estimation performed by Cahn and Trilling, $\Gamma = 0.9 \pm 0.3$ MeV [37], based on the previously published DIANA data [38]. The big change is explained mainly by the difference in the assumptions of the two estimations. Cahn and Trilling assumed, that the $\Theta(1540)^+$ is rescattered in the nucleus with the the same probability as the non-resonant pK^+ pair; while DIANA assumed that the $\Theta(1540)^+$ is not rescattered in the nucleus. Note, that the Belle upper limit, $\Gamma < 0.64$ MeV (90% C.L.) [39], was obtained under the Cahn and Trilling assumption. To recalculate it under the DIANA assumption, the upper limit should be multiplied by the probability that the non-resonant pK^+ pair, produced in the nucleus, does not rescatter inside this nucleus. Rough estimates give a factor of 1/2 for light nuclei, which leads to the upper limit $\Gamma \lesssim 0.3$ MeV. Thus some inconsistency between DIANA and Belle persists also if their results are compared under the assumption that the $\Theta(1540)^+$ is not rescattered in the nucleus.

In the new analysis DIANA found that the signal of the $\Theta(1540)^+$ is concentrated in the rather narrow interval of the incident K^+ momentum $0.445 < p_{K^+} < 0.525$ GeV/c. This fact was surprising for the author of this review. From a simple Monte-Carlo simulation, which was verified on the secondary interactions of the kaons in the material of the Belle detector, we obtain that additional 30% of the signal events should be contained in the interval $p_{K^+} > 0.525$ GeV/c at DIANA. (The incident kaon momentum spectrum of DIANA was used as an input; the difference in the Fermi-momentum distributions for xenon nucleus at DIANA and for light nuclei at Belle was taken into account). The absence of the

$\Theta(1540)^+$ signal at DIANA in the $p_{K^+} > 0.525 \text{ GeV}/c$ interval corresponds to the downward fluctuation of about 3σ . We conclude that the evidence for the $\Theta(1540)^+$ from DIANA is not strong.

The NOMAD Collaboration searched for the $\Theta(1540)^+$ production in the $\nu_\mu N$ interactions [40]. The $\Theta(1540)^+$ signal was not observed and an upper limit on the $\Theta(1540)^+$ production rate of $2 \cdot 10^{-3}$ per neutrino interaction (90% C.L.) was set. Preliminary NOMAD results, quoting the $\Theta(1540)^+$ signal with a 4.3σ significance [41], suffered from an incorrect background estimation. The results reported in [41] were obtained using harder proton identification requirements which yielded an increase in the proton purity from 23% to 51.5% with about a factor six loss in the statistics. It is interesting to compare the NOMAD result [40] with the analysis of the bubble chamber neutrino experiments which provide an estimation of the $\Theta(1540)^+$ production rate as large as $\sim 10^{-3}$ events per neutrino interaction [42]. As shown in Fig.15, for a large fraction of the x_F range, except in the region $x_F \approx -1$, such a value is excluded.

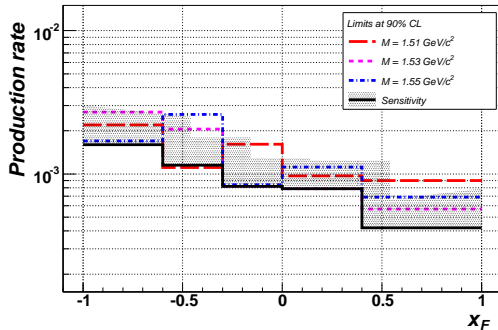


FIG. 15: Sensitivity and upper limits at 90% C.L. for the $\Theta(1540)^+$ production rates at NOMAD [40] as a function of x_F , for the $\Theta(1540)^+$ masses of 1510, 1530 and 1550 MeV/c^2 .

The COSY-TOF Collaboration repeated the experiment studying the $pp \rightarrow pK^0\Sigma^+$ reaction with substantially improved statistical accuracy and extended detection capability [43]. For the new measurement a slightly higher beam momentum was chosen ($3.059 \text{ GeV}/c$ instead of $2.95 \text{ GeV}/c$) to move the upper bound of the pK^0 mass further away from the expected $\Theta(1540)^+$ signal. No evidence for a narrow resonance in the pK^0 spectra was found and the upper limit on a cross section $\sigma < 0.3\mu\text{b}$ (95% C.L.) was set for the mass region of $1.50 - 1.55 \text{ GeV}/c^2$. It was also concluded that in the previous measurement [44] the background level had been underestimated and that the significance of the $\Theta(1540)^+$ signal is much lower than claimed in the previous publication.

The H1 Collaboration searched for the $\Theta(1540)^+$ production in the deep inelastic ep scattering [45]. No signal was found and the mass dependent upper limit on the

cross-section was set. In the same reaction the ZEUS Collaboration reported an evidence of the $\Theta(1540)^+$ production [46], with the preliminary cross-section measurement $\sigma(ep \rightarrow e\Theta(1540)^+X \rightarrow epK^0X) = 125 \pm 27_{-28}^{+38} \text{ pb}$ for $Q^2 > 20 \text{ GeV}^2$ and $0.04 < y < 0.95$ [47]. The H1 upper limit, recalculated into the ZEUS kinematic region, is $\sigma(M = 1.52 \text{ GeV}/c^2) < 100 \text{ pb}$ (95% C.L.) [48]. Thus the results of ZEUS and H1 are in conflict.

The most significant $\Theta(1540)^+$ signal to date is from the SVD-2 Collaboration, which considerably increased the statistics and was able to confirm its earlier observation of the $\Theta(1540)^+$ production in the proton nucleon interactions [49]. The statistical significance of the $\Theta(1540)^+$ signal at SVD-2 is at the level of 8σ . The SPHINX experiment, which operated exactly in the same environment, found null result [50]. It was claimed, however, that at SVD-2 the $\Theta(1540)^+$ is produced with very small x_F , while SPHINX has no acceptance in this region. Still, it is not clear how to reconcile the SVD-2 positive result with the null result of the HERA-B Collaboration [51], which was obtained for the same reaction, with the same acceptance in x_F but with the center-of-mass energy 40 GeV instead of 12 GeV. The SVD-2 yield ratio $\Theta(1540)^+/\Lambda(1530) = 8 - 12\%$ is in marked disagreement with the upper limit from HERA-B, $\Theta(1540)^+/\Lambda(1530) < 2.7\%$ (95% C.L.). A comparison with the CDF upper limit $\Theta(1540)^+/\Lambda(1530) < 3\%$ (90% C.L.) [52] should also be valid, since for the central production the difference in the nucleon-nucleon center of mass energy is not important.

There are a few other new results on the searches for the $\Theta(1540)^+$ [53] none of which finds a significant signal.

The DIANA evidence for the $\Theta(1540)^+$ [36] looks the most convincing among all positive results, but it is not strong.

We do not consider here candidates for other pentaquarks, since there were no new positive results on them and since the evidence for their existence is actually negated [1].

To summarize, for any evidence of the $\Theta(1540)^+$ there is another result, which was obtained in similar conditions, with similar sensitivity but without the $\Theta(1540)^+$ signal. The experimental evidence for the $\Theta(1540)^+$ is very weak.

In summer 2007 the LEPS Collaboration completed the collecting of a new data sample with the increase of the statistics by a factor of 3. It is very intriguing to see the results of the analysis of new data. Also, new data of HERA-II are being analyzed.

In conclusion, there is an impressive progress in the heavy flavor baryons over the last two years. The number of known states changed from 12 to 18 for charmed baryons and from one to four for beauty baryons. Theoretical predictions for the masses of the new ground state baryons are in agreement with experimental mea-

surements. Synergy between theory and experiment is required to determine the spin and parity for the new excited charmed baryons.

The experiments on heavy flavot baryons are consistent and the experimental results are robust.

The experimental evidence for the $\Theta(1540)^+$ pentaquark is weak. There appeared more null results since the PDG2006 review. The new estimation of the $\Theta(1540)^+$ width is extremely low, $\Gamma = 0.36 \pm 0.11$ MeV, which makes its observation in the experiments with production channels virtually impossible and puts new challenges to theory. New results are expected from LEPS and HERA-II.

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